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MECHANICAL DESIGN ENGINEERING

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ADVANCED DESIGN PROGRAM

# LUNAR CRANE HOOK

JUNE 1988

ORIGINAL CONTAINS
COLOR ILLUSTRATIONS

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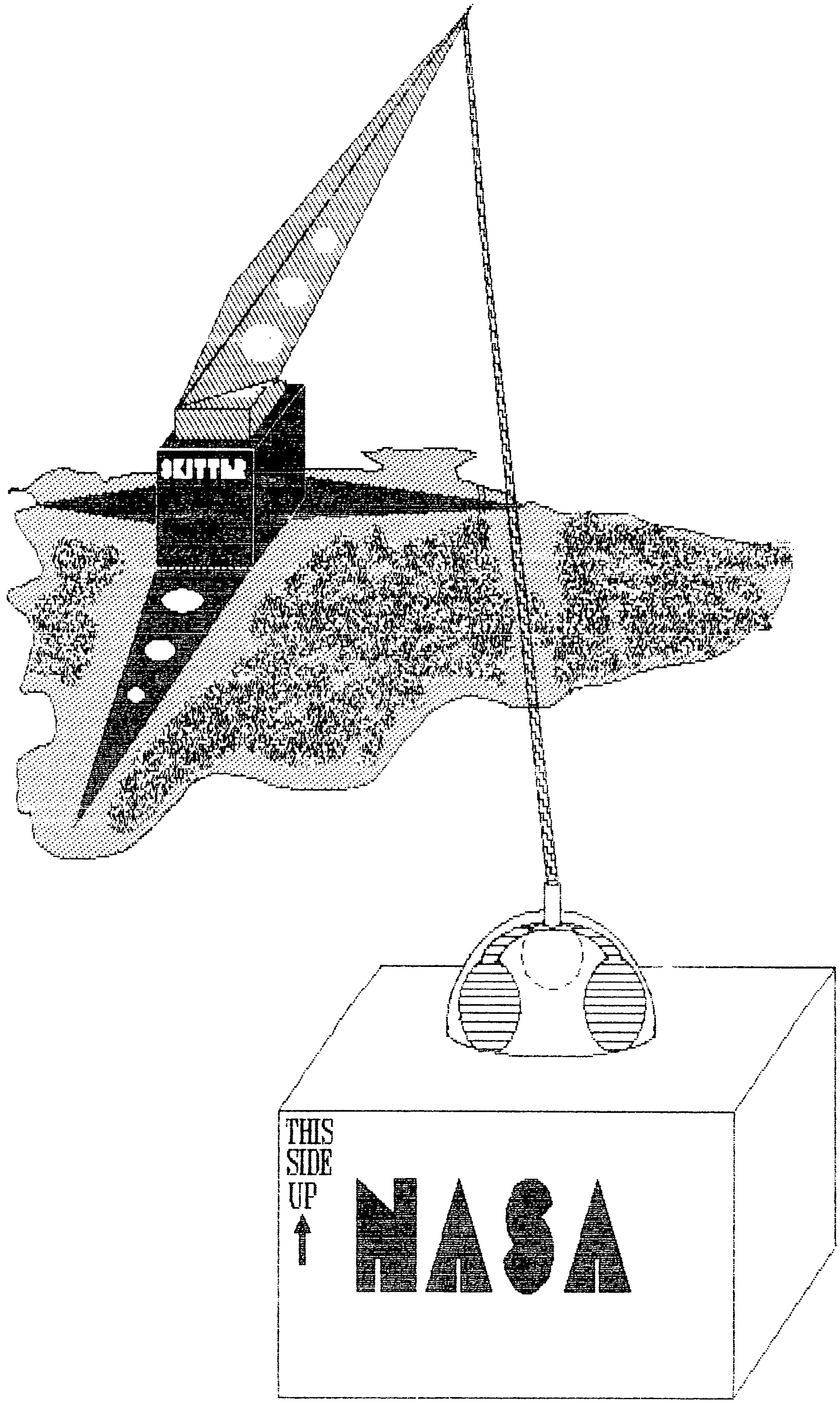
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## ABSTRACT

The base and ball hook system is an attachment that is designed to be used on the lunar surface as an improved alternative to the common crane hook and eye system. The Design proposed uses an omni-directional ball hook and base to overcome the design problems associated with a conventional crane hook. The base and ball hook is not sensitive to cable twist which would render a robotic lunar crane useless since there is little atmospheric resistance to dampen the motion of an oscillating member. The symmetric characteristics of the ball hook and base eliminates manual placement of the ball hook into the base; commonly associated with the typical hook and eye system. The major advantage of the base and ball hook system is it's ease of couple and uncouple modes that are advantages during unmanned robotic lunar missions.

# PROBLEM STATEMENT

## BACKGROUND AND PERFORMANCE OBJECTIVES

SKITTER will use a series of implements to perform different tasks on the moon. Among the implements that SKITTER will be using is the boom crane. There is a need for a reliable way to remotely connect and disconnect the loads that are to be lifted by the crane. The hook will need to be mechanically simple to aid in connection due to the time delay of the commands due to the distance the information must travel, from the Earth to the Moon.

## GEOPHYSICAL CONSTRAINTS

Due to the moon's geophysical characteristics (dusty environment, drastic temperature range, lack of atmosphere, and a gravitational force which is 1/6 that of the earth), a crane hook that will perform under theses conditions is an imperative need.

### Gravity

Although the diameter of the moon is about one-quarter that of the earth, the moon weighs only about one-eightieth as much as the earth. The force of gravity at the moon's surface is only one-sixth that of the earth. Therefore, a cargo load weighing approximately 350 pounds on the earth weighs only about 60 pounds on the moon. This fact most be considered when designing a crane hook.

### Atmosphere

The moon has no atmosphere because it's gravity is too weak to hold an atmosphere like the earth's. If relatively light gases like oxygen, nitrogen, and water vapor were ever present on the moon, their molecules must have escaped into space long ago. The gravity of the moon is strong enough to hold back heavier atoms like argon and radon, but there are not enough of these elements present to make any tangible atmosphere. Due to this lack of atmosphere, liquids evaporate on the moon. This creates a constraint during the design process when lubricants are a concern. Also, since there is no humidity, the moon's soil is dry and very dusty.

### Radiation

The lack of atmosphere on the moon means that, unlike the earth, the surface of the moon has no protection from continuous bombardment by tiny meteorites and from scorching by lethal X-rays, gamma rays, and cosmic rays that originate from the sun and the rest of the universe. This fact is an important consideration during the materials selection of the design process. Most metals are not very susceptible to ultra-violet radiation. However, polymers are sensitive and should be shielded.

### Temperature

As the moon moves around the earth, it turns so slowly that it always keeps the same side facing toward the earth. The moon thus rotates once on its axis in the same time that it makes one trip around the earth. To keep one face turned always to the earth, the moon must turn its back on the sun during half its orbit.

As a result of these motions, the 29 and 1/2 - day month is divided on the moon into a lunar "day" and a lunar "night," each about two weeks long. Because the moon has no insulating atmosphere, the "daytime" temperature in direct sunlight is approximately 134° C. (270° F.), well above the boiling point of water. During the lunar "night," the temperature drops suddenly (200° C per minute) to about -170° C. (-270° F.), much colder than the freezing point of carbon dioxide ("dry ice").

## MECHANICAL CONSTRAINTS

The hook should be able to be hooked from any direction without concern for orientation. The base and ball hook system must be operated without the manual assistance of a person on the moon.

## OVERVIEW OF SKITTER

SKITTER (Spacial Kinematic Inertial Translatory Tripod Extremity Robot).is a three-legged transport vehicle designed to perform under the unique environment of the moon. In order to achieve the simplest mechanical system possible, design engineers considered the most simple statically stable device, the tripod. Three legs, arranged at 120 degree intervals, and a central platform, make up the structure. A femur link and tibia, terminating as foot, comprise each leg.

Electromechanical actuators serve as the hip and knee joints. The hip joint alters the angular position of the femur relative to the platform. The knee joint changes tibia position relative to the femur.

Operation involves a closed-loop velocity feedback system and a master/slave relationship between controlling devices. Each slave, a dedicated microprocessor, calculates link velocity based on input from its respective position sensor. Results are compared to the prescribed velocity for that particular position while the error signal, conditioned by the gain, governs actuator motion.

The master, a remote human operator and/or on-board computer, coordinates slave action to achieve a variety of platform positions. Actuating a single leg, for example, forces the platform to lean from its equilibrium position - maneuver for zeroing in on targets. The same procedure, applied to the other legs, lowers the platform close to, or with enough iterations, directly onto, an implement .

To traverse distances, move radially, or rotate about a single point, the mobile platform makes use of the moon's low gravitational force. Each leg pushes off from the surface, changes position, and falls back into contact with the surface at a new point.

The three-legged platform offers several advantages over their lunar vehicle concepts, according to its designers, Jim Brazell, Brice MacLaren, and Gary McMurray of Georgia Institute of Technology. SKITTER which can be used as a transportation or carrying cargo device is very versatile. [1]

1. David J. Bak, "Three legs make mobile platform " Design News, February 15, 1988, page 136.

## DESCRIPTION

The Lunar Crane Hook System is comprised of two main components- the base and ball hook. The base will be capable of being attached to the cargo in a variety of configurations. Additionally, the system can be affixed to the load to account for various load geometries. The ball hook is attached to the end of the crane's cable and can be guided into the base at which point the load can be lifted and moved to another location. The base is comprised of three components: the base plate, the ribs, and the dome.

Base Plate: The base plate provides a structural link between the cargo and the load bearing members of the crane hook system. the bottom surface of the disk bearing members, i.e. ribs and dome, are fastened

Ribs: Three ribs, attached to the base plate at 120 degrees intervals, provide the structure which bears the majority of the load. The shape of the ribs consist of three important radii: the outside radius, and upper, lower inside radii. The outside radius is connected to the outside dome which increases the load bearing capacity of the base structure. The two inside radii facilitate ease of ball hook engagement. The lower inside radius helps to position the ball hook over the center of the base plate, while the upper radius functions as a lock to hold the ball hook in place when the cable is tensioned and under load.

Dome: The dome consists of three segments which are attached to the three ribs and the bottom perimeter of the base plate. Each segment is centered over and fastened to its corresponding rib. The shape of the solid dome is such that the ball hook will be guided between two of the segments and into the center of the crane hook system as the crane cable is tensioned. The curved outer surface of the dome will assist in guiding the ball hook towards the doorways and into the structure of the base and internal ribs. The spherical shape of the dome also decreases the possibility of the base being caught in the lunar soil.

The ball hook is a spherical fixture that attaches to the end of the crane cable and engages the base. The ball hook is solid and has a upper cable shank. The upper cable shank prevents the cable from entangling in the base and cargo. A step by step graphic of the attachment of the hook to the base mount is **Figure 1**.

## INTRODUCTION

The base and ball hook system is an attachment that is designed to be used on the lunar surface as an improved alternative to the common crane hook and eye system. The base and ball hook system is a direct replacement item that can be attached to a crane cable used for the hook and eye.

The major advantage of the base and ball hook system is it's ease of couple and uncouple modes that are advantages during unmanned robotic lunar missions. The symmetric characteristics of the ball hook and base eliminates manual placement of the ball hook into the base; commonly associated with the typical hook and eye system. The base and ball hook is not sensitive to cable twist which would render a robotic lunar crane useless since there is little atmospheric resistance to dampen the motion of an oscillating member.

The base and ball hook can be attached in the same conventions as the hook and eye system therefore, a number of cargo items can be lifted effectively and in the same manner. The base and ball hook system can also be applied to use on earth as an alternative to general crane hooks used in construction or any cargo application needing to be transported by a cable.

## MECHANICAL CONSTRAINTS

Motion of the crane's boom is limited to the adjustments in altitude angle and azimuth angle. Adjustments in the hook position are obtained through boom movements as well as through the adjustment of the free length of cable. Additionally, the base and ball hook system must be operated without the manual assistance of a person on the moon.

## MATERIALS/FABRICATION

Due to the geophysical constraints inherent to the lunar surface, it is necessary to select a material which displays good strength characteristics and resistance to corrosion and environmental attack. Additionally, the material should not be adversely affected by the extremes in temperature which are encountered on the lunar surface. Also, since launch costs are considerable, a high strength to weight ratio is important.

It was found that an Aluminum alloy (6061-T6) possessed many of the physical properties that are tolerable to the lunar environment. This aluminum alloy(6061-T6) consists of the following components: 1% Mg, 0.6% Si, 0.25% Cu, ).20% Cr, the metal is also solution heat treated and artificially aged. The density of the alloy is 0.098 lb/in3 and has a tensile strength of 45 ksi and an ultimate yield strength of 39 ksi. Thus, through the alloying process, aluminum can obtain strengths twice that of mild steel. This alloy has one of the highest strength to weight ratio and can be compared to superalloy steels and titanium. 6061-T6 also has a low coefficient of thermal expansion ($B$=0.005 in/in) for the range -250 F to 210 F and thus will retain its shape over a wide range of temperatures. Aluminum alloys also exhibit excellent cryogenic properties and actually become tougher at lower temperatures, whereas most steels become brittle at cryogenic temperatures.

Although aluminum is a highly chemically active metal, it possesses an excellent resistance to corrosion. This resistance is due to a natural forming film that bonds to the surface of the material. This film is transparent and thus does not detract from the reflectiveness of the aluminum. This reflectiveness can be useful in maintaining a constant temperature across the dome.

The various components of the base- baseplate, ribs, dome, can be attached to each other by solid state and fusion welding processes.

## STRUCTURAL

Both designs for the hook base were created as solid models on the System Dynamics Research Corporation's (SDRC) I-DEAS system, using GE Apollo terminals. The models were constructed as three solid ribs, each making up one third of the hook base. The base plate was not modeled, since in the analysis it would be represented only as restraining forces on the bottom of the hook section.

**Rounded Base**

The first model was the **rounded base**, which was basically a half sphere which was cut out to provide appropriate pathways for the passage of the hook. (**Figure 2**)

After this solid had been modeled, a one third (120°) section was passed to the **Supertab** module of I-DEAS for finite element analysis. The nodes and elements were generated using the Free Mesh Geometry and Free Mesh Generation tasks of Pre/Post Processing.

Next, the load and restraint sets were attached to the appropriate nodes on the finite element model, as follows:

* All the nodes which would be in contact with the base plate were constrained against motion in the x, y, and z directions, and against rotation about any of the three axes.

* A worst case load of 4000 lbs was placed at a 45° angle on the tip on the surface which would be in contact with the hook.

Once these load cases were assigned to the model, the entire system was transferred to the Model Solution module, where it was run with a selected output of linear static displacement and stresses. Total run time was about 20 minutes from start to finish.

Using the analysis datasets generated by the Model Solution, picture files were then produced showing the deformed geometry of the model, and the stress concentration contours (**Figures 3 and 4**).

A report summary was printed on the for the results of nodal displacement and stresses (the complete version is included in the **Appendix**), and the general results were:

* The average nodal stresses were:

| | |
|---|---|
| Maximum Principal: | 5909 psi |
| Maximum Shear: | 4191 psi |
| Von Mises: | 7713 psi |

* The maximum principal stress on the model was 33100 psi, which **Figure 4** shows occurring near the base plate.

* The average nodal displacement was:

| | | |
|---|---|---|
| 0.002852 | X | inches |
| 0.006886 | Y | |
| -0.00631 | Z | |

* The maximum displacement was at the top of the model (**Figure 3**): a total of 0.0582 inches in the direction of the force.

Based on this analysis, the rounded hook can bear the load with out failure, but the lack of stress in the upper portion suggests that there is material which serves no purpose.

**Tapered Base**

The results of the analysis on the rounded base suggested that a smaller version might be designed which used less material, yet had most of its components along the line of force. Consequently, a second design, the **tapered base** was created using the same methods as on the rounded base (**Figure 5**).

After this solid had been modeled, a one third (120°) section was again passed to the **Supertab** module of I-DEAS for finite element analysis. The nodes and elements were similarly generated using the Free Mesh Geometry and Free Mesh Generation tasks of Pre/Post Processing.

The load and restraint sets were attached to the appropriate nodes on the finite element model, as below:

* All the nodes which would be in contact with the base plate were constrained against motion in the x, y, and z directions, and against rotation about any of the three axes. This was

the same restraint imposed on the rounded base.

* A worst case load of 4000 lbs was again placed at a 45° angle on the tip on the surface which would be in contact with the hook.

Having assigned these load cases to the model, the entire system was transferred to the Model Solution module, where it was run with a selected output of linear static displacement and stresses. Total run time was about 10 minutes from start to finish, since this model required fewer nodes for its smaller volume..

Using the analysis datasets generated by the Model Solution, picture files were then produced showing the deformed geometry of the model, and the stress concentration contours (**Figures 6 and 7**).

As previously, a report summary was printed on the for the results of nodal displacement and stresses (the complete version is included in the **Appendix**), and the general results were:

* The average nodal stresses were:

| | |
|---|---|
| Maximum Principal: | 23400 psi |
| Maximum Shear: | 23450 psi |
| Von Mises: | 42280 psi |

* The maximum stress on this model occurred along the curved inner surface (**Figure 7**). The Maximum Principal Stress at this point was 61800 psi -- which clearly suggests that failure had begun in this area.

* The average nodal displacement was:

| | | |
|---|---|---|
| 0.01972 | X | inches |
| 0.0304 | Y | |
| -0.0742 | Z | |

* The maximum displacement was at the top of the model (**Figure 6**): a total of 0.363 inches in the direction of the force.

The results of this analysis demonstrate a need for reinforcement if such a tapered hook base arrangement is to be used. Although serious failure had begun in the model, the displacements

The results of this analysis demonstrate a need for reinforcement if such a tapered hook base arrangement is to be used. Although serious failure had begun in the model, the displacements at the top were still not enough to allow the hook to tear free of the base mount, but further loading on the deformed model might lead to complete failure.

### Compromise Design

Analysis of the two hook mount designs suggests that neither design is optimal for the performance criteria, although each has desirable traits. An alternative design would be the tapered base, with the addition of a reinforcing rib along the back surface (**Figure 8**). Such a design might well reduce the stress concentrations which led to the failure of the tapered model, and the rib would add much less additional weight than in the rounded rib arrangement. To preserve the desirable hemispherical outer surface, which helps to guide the hook to a hole in the mount, a thin, non-functional shell might be placed over the compromise design solid ribs.

## WEIGHT/MASS/INERTIA

NOTE: For each of the hook base designs, a solid model was created using the SDRC I-DEAS software package, on GE Apollo terminals. Analysis was confined to a solid representing one third of the total hook base, so the figures below apply only to this modeled one third section.

| PART | MASS (lbm) | WEIGHT(E) (lbf) | WEIGHT(M) (lbf) |
|---|---|---|---|
| Rounded Base | 0.105 | 3.382 | 0.564 |
| Tapered Base | 0.039 | 1.259 | 0.2098 |

| PART | CENTER OF GRAVITY: X | Y | Z |
|---|---|---|---|
| Rounded Base | 1.576 | 2.12 | -2.795 |
| TapereD Base | 1.077 | 2.446 | -1.866 |

| MOMENT OF INERTIA: | XX | YY | ZZ | XY | YZ | ZX |
|---|---|---|---|---|---|---|
| Rounded Base | 9.03 | 8.20 | 10.61 | -1.07 | 1.49 | 1.35 |
| Tapered Base | 4.13 | 1.37 | 4.38 | -0.28 | 0.49 | 0.23 |

**PERFORMANCE**

The main advantage of this system is it's maximum ease of attachment and detachment with a minimum amount of energy required by SKITTER'S crane arm. The crane can be secured from any one of three directions about the crane hook base. The base will be mounted to the cargo in such a manner as to allow for maximum access by the crane hook ball. In order to obtain maximum access the base will be mounted to the cargo as described in the cargo attachment section of this analysis.

The base provides three entryways which can be accessed by the crane hook ball. These entryways are situated at 120 intervals about the base. The ball must be guided into one of the entryways. Once the ball is inside the dome of the base the sides of the ribs will guide it toward the center of the dome as tension is applied to the crane hook line. When the ball reaches the center of the dome it becomes locked in place from movement up or to any side. The only way the ball can be freed is if tension is let off of the crane line. The ball will then lower out of the locking area and can be guided out either of the three entryways.

This system can be used with the base in a position parallel to the moon's surface or tilted at an angle from horizontal. In order to attach the base in a tilted situation, the ball must be guided into an entryway and tension must be applied to the crane line until the ball reaches the locked position.

Another major advantage of this system is that in the event of uncontrolled crane line swings the crane hooks ball's spherical design will prevent it from hooking to other SKITTER components. A conventional cargo hook does not have this advantage. it would be very likely to hang up on other parts.

The maximum load capacity of the crane hook system is 2000 lb. On the moon this figure will be 12000 lb.

## ATTACHMENT

The base can be attached to a variety of cargo geometries and weights. It can be used as a permanent fixture on cargos that are moved frequently or as a temporary hoist that can be removed from the cargo. A temporary base hoist can be strapped to a cargo load and removed when the cargo has been repositioned. In all cases when a single base is used, it is most desirable to have the base located at the center of gravity to prevent extreme tipping of the cargo which could cause detachment of the base from the hook.

When used as a permanent lift attachment the base plate can be fastened by bolts or welded to the cargo. Also the base can be integrated into the structure of the item being hoisted. For example, an instrument requiring frequent transport can have a base designed into the instrument's support frame thus, lifting stresses can be evaluated and damage resulting from transport can be eliminated.

A temporary base hoist can be strapped to a cargo load and removed when the cargo has been repositioned. Cables can be added to the base with the cables attached to the cargo. Doing this would require the addition of legs and a ring to the bottom of the dome. The legs need to extend out from the base to aid in the stability of the base while uncoupling it from the hook. Cables would be attached to the ring and to the cargo. This method would allow for more stability for larger loads. Other methods for temporarily mounting a base are a twist lock, or a screw thread connection.

When a base can not be effectively attached to the cargo's center of gravity more than one base can be used on a single cargo item. When a dual base and ball hook system is used the cargo has increased stability and the system has an increase in load capacity.

## OPERATION

The design of the crane hook system is such that all steps of the operation can be controlled from a remote location. With controls to manipulate the SKITTER crane boom, the operator on Earth can utilize the video system of SKITTER to guide the ball hook into position. Since there are three openings in the dome into which the ball can be maneuvered, at least one opening will always be visible. The ball hook is moved into one of the openings by the simple movements of the boom (altitude, azimuth and angle adjustments) and by adjusting the free length of cable. As the ball hook is lifted, the interior shape of the dome will lead the ball to its centered position. Further lifting of the ball hook will cause the ball to move into the lock and lift position. It is at this point that the crane hook system with load attached can be lifted off the lunar surface and moved to its new position.

During the time that the cargo is lifted, the ball hook is securely held in the dome by the weight of the cargo and the ball hook will remain in place even if the load shifts and causes the crane hook system to tilt.

Uncoupling of the ball hook by relieving the tension in the cable and thus allowing the ball hook to drop out of the lock and lift position. Subsequent boom movement will move the ball hook out of the dome to complete the uncoupling process.

## FAILURE

The crane dome is designed to resist a cable tension of 4000 lbf. This force will cause the base to fail first, keeping the crane.from failing. The only other foreseen means of failure would be the ball becoming unhooked from the dome and cargo. The placement of the dome near the center of gravity will prevent any major tipping of the cargo. In the extreme case of tilt the ball and dome will stay hooked until the cargo reaches an angle of 85 degrees from the horizontal plane. As long as the load that are moved are of a safe weight ,this system should assure a completely reliable way of transporting cargo with a crane.

## CONCLUSIONS

After computer aided analysis and testing of the physical model, it has been determined that the Lunar Crane Hook System is a practical solution to the problem which would arise if an ordinary crane hook was used on the lunar surface. The revised geometry model, which incorporated features of both preliminary designs, should be close to an optimal arrangement, but further stress analysis would be required to confirm its usefulness. Regardless of the specific solid rib geometry used, the total hook and mount system meets the performance criteria and constraints and the design of the ribs need only be refined for this system to be ready for final development and implementation.

The Lunar Crane Hook System provides a simple and reliable method with which cargo can be moved on the lunar surface. The system can be remotely operated when aided only by a video camera set-up and can be attached to the cargo in a number of configurations. The ease of attachment should greatly abet the use of this hook system, even with the feedback delays imposed by transmission times from Earth to the Moon. The ability of this arrangement to compensate for non-standard angles of attachment also aides the remote operator of SKITTER, as does the fact that the system can work with a diverse array of load geometries.

## ACKNOWLEDGEMENTS

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Virgil McConnell - Shop Assistant, School of Mechanical Engineering, Georgia Tech.

Butch Cabe - Shop Assistant, School of Mechanical Engineering, Georgia Tech.

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Peck and Hale - Container securing hooks 4017-2431

Sea Spike Anchors Inc- folding anchor 4017-2748

Hamamaka International-retrieving hardware; grapel hook 4017-4231

Brodertick & Bascom Rope Co-double loop bridle sling 7342-1093

The Crosby Group-Byron Jackson Unimatic Hook 7342-1656

# APPENDIX

A. Analysis Datasets from I-DEAS Model Solutions
- Displacement Summary -- Rounded Base
- Stress Summary -- Rounded Base
- Displacement Summary -- Tapered Base
- Stress Summary -- Tapered Base

B. Figures



C. Decision Matrix: Crane Hook Design

D. Progress Reports

E. Disclosure of Invention

F Graphics of the Week

# APPENDIX A
# ANALYSIS DATASETS

30-MAY-88 21:02:06

SDRC I-DEAS 3.8a: Pre/Post Processing
LARGER FLARED HOOK
DEFORMED GEOMETRY OF LARGER HOOK

Group ID : PERMANENT GROUP2
Analysis Dataset : 2 - Case 1,Load 1,Displacements
Report Type : Criterion
Dataset Type : Displacements
Frame of Reference : Global
Data range : Above Data Value

Units : IN
Load Set : 1
Data Component : Magnitude
Upper Value : 0.0000E+00

| | Displ-X | Displ-Y | Displ-Z | Rot-X | Rot-Y | Rot-Z |
|---|---|---|---|---|---|---|
| | 9 | 8 | 258 | 1 | 1 | 1 |
| Maximum | 1.364E-02 | 3.512E-02 | 4.036E-04 | 0.000E+00 | 0.000E+00 | 0.000E+00 |
| | 341 | 154 | 9 | 1 | 1 | 1 |
| Minimum | -7.058E-04 | -5.816E-04 | -3.149E-02 | 0.000E+00 | 0.000E+00 | 0.000E+00 |
| Average | 2.852E-03 | 6.886E-03 | -6.311E-03 | 0.000E+00 | 0.000E+00 | 0.000E+00 |

1



SDRC I-DEAS 3.8a: Pre/Post Processing 30-MAY-88 21:05:20
LARGER FLARED HOOK
STRESSES ON LARGER HOOK

Group ID : PERMANENT GROUP2
Analysis Dataset : 3 - Case 1,Load 1,Stresses
Report Type : Criterion
Dataset Type : Stress
Frame of Reference: Global
Surface Type : Top
Data range : Above Data Value

Units : IN
Load Set : 1
Data Component: Max Prin
Upper Value : 0.0000E+00

| | Max Prin | Mid Prin | Min Prin | Max Shear | Von Mises |
|---|---|---|---|---|---|
| | 265 | 265 | 265 | 232 | 232 |
| Maximum | 9.238E+04 | 4.277E+04 | 3.723E+04 | 5.826E+04 | 1.009E+05 |
| | 5 | 5 | 232 | 51 | 51 |
| Minimum | -1.121E+04 | -2.022E+04 | -6.589E+04 | 3.248E+02 | 5.631E+02 |
| Average | 5.909E+03 | 9.902E+02 | -2.473E+03 | 4.191E+03 | 7.713E+03 |

1



SDRC I-DEAS 3.8a: Pre/Post Processing 30-MAY-88 15:20:40
TAPERED HOOK ANALYSIS
DEFORMED GEOMETRY OF OPTIMIZED HOOK

| | | | |
|---|---|---|---|
| Group ID | : PERMANENT GROUP2 | | |
| Analysis Dataset | : 2 - Case 1,Load 1,Displacements | | |
| Report Type | : Criterion | Units | : IN |
| Dataset Type | : Displacements | Load Set | : 1 |
| Frame of Reference | : Global | Data Component | : Magnitude |
| Data range | : Above Data Value | Upper Value | : 0.0000E+00 |

| | Displ-X | Displ-Y | Displ-Z | Rot-X | Rot-Y | Rot-Z |
|---|---|---|---|---|---|---|
| | 35 | 19 | 96 | 1 | 1 | 1 |
| Maximum | 7.144E-02 | 1.790E-01 | 2.497E-06 | 0.000E+00 | 0.000E+00 | 0.000E+00 |
| | 45 | 88 | 4 | 1 | 1 | 1 |
| Minimum | -4.073E-04 | -1.562E-02 | -2.568E-01 | 0.000E+00 | 0.000E+00 | 0.000E+00 |
| Average | 1.972E-02 | 3.040E-02 | -7.420E-02 | 0.000E+00 | 0.000E+00 | 0.000E+00 |

1



SDRC I-DEAS 3.8a: Pre/Post Processing 30-MAY-88 15:40:13
TAPERED HOOK ANALYSIS
STRESSES ON OPTIMIZED HOOK

Group ID : PERMANENT GROUP2
Analysis Dataset : 3 - Case 1,Load 1,Stresses
Report Type : Criterion
Dataset Type : Stress
Frame of Reference: Global
Surface Type : Top
Data range : Above Data Value

Units : IN
Load Set : 1
Data Component: Max Prin
Upper Value : 0.0000E+00

| | Max Prin | Mid Prin | Min Prin | Max Shear | Von Mises |
|---|---|---|---|---|---|
| | 89 | 89 | 55 | 87 | 87 |
| Maximum | 2.091E+05 | 6.643E+04 | 4 161E+04 | 1.295E+05 | 2.284E+05 |
| | 46 | 88 | 88 | 2 | 2 |
| Minimum | -2.502E+04 | -5.743E+04 | -1.921E+05 | 0.000E+00 | 0.000E+00 |
| Average | 2.340E+04 | 8.933E+02 | -2.349E+04 | 2.345E+04 | 4.228E+04 |

# APPENDIX B
# FIGURES

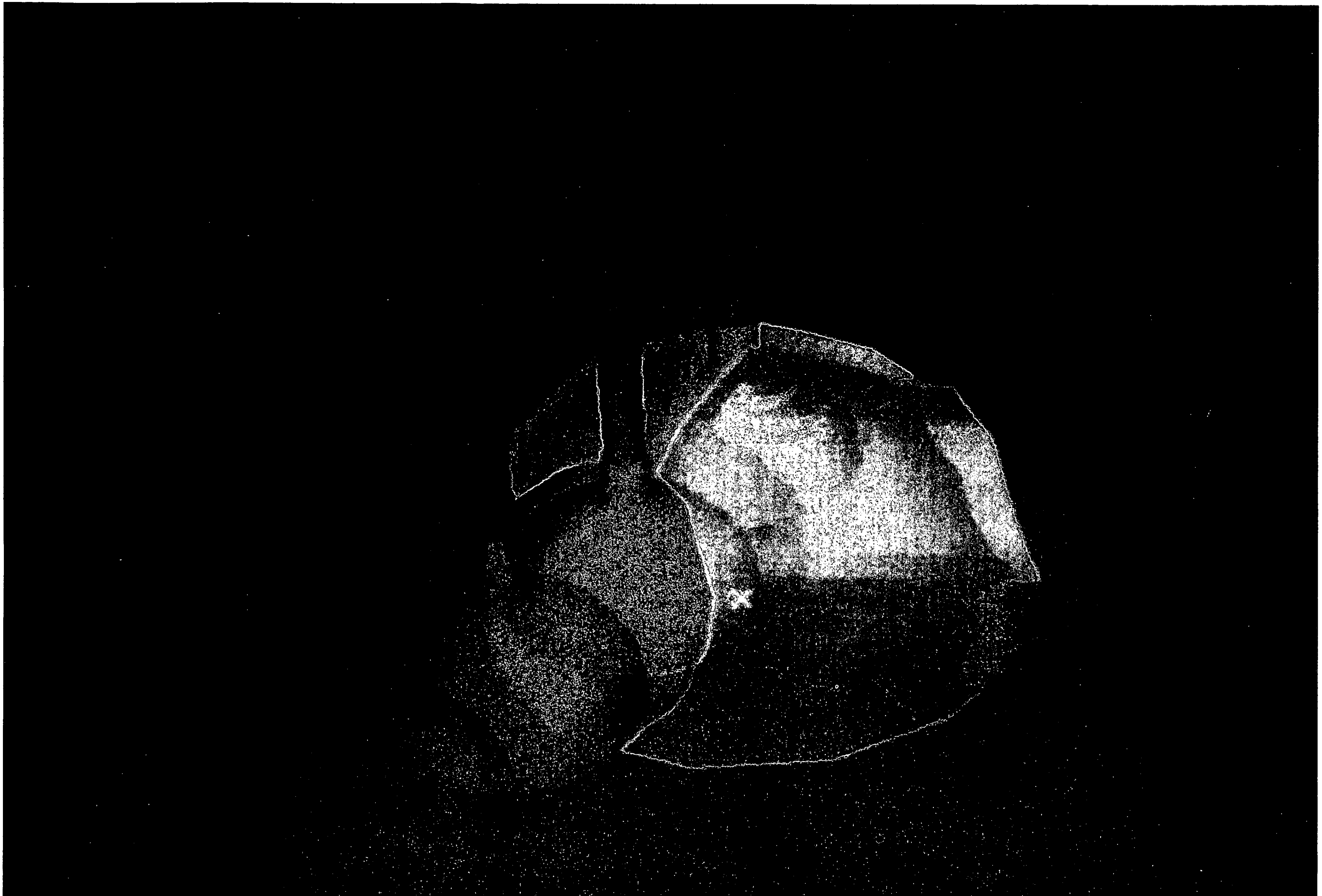


Figure 1


SDRC I-DEAS 3.8a: Object Modeling
TAPERED HOOK ANALYSIS
VIEW:none, none
Task: OBJECT
Object: 11-A
30-MAY-88
DISPLAY:none, none
Bin: 1-MAIN
Y
Z
X
Process_6

Figure 2

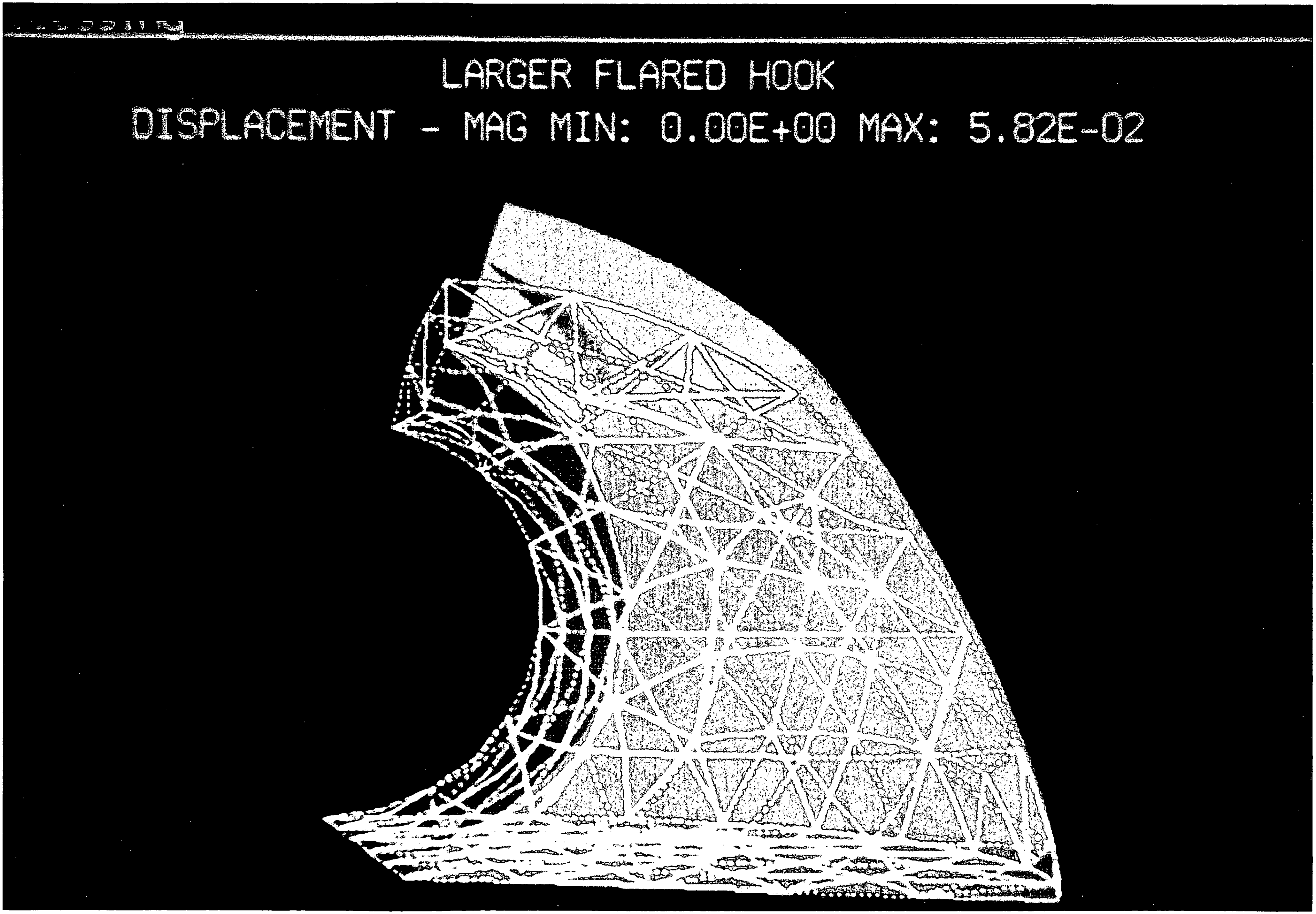



Figure 3

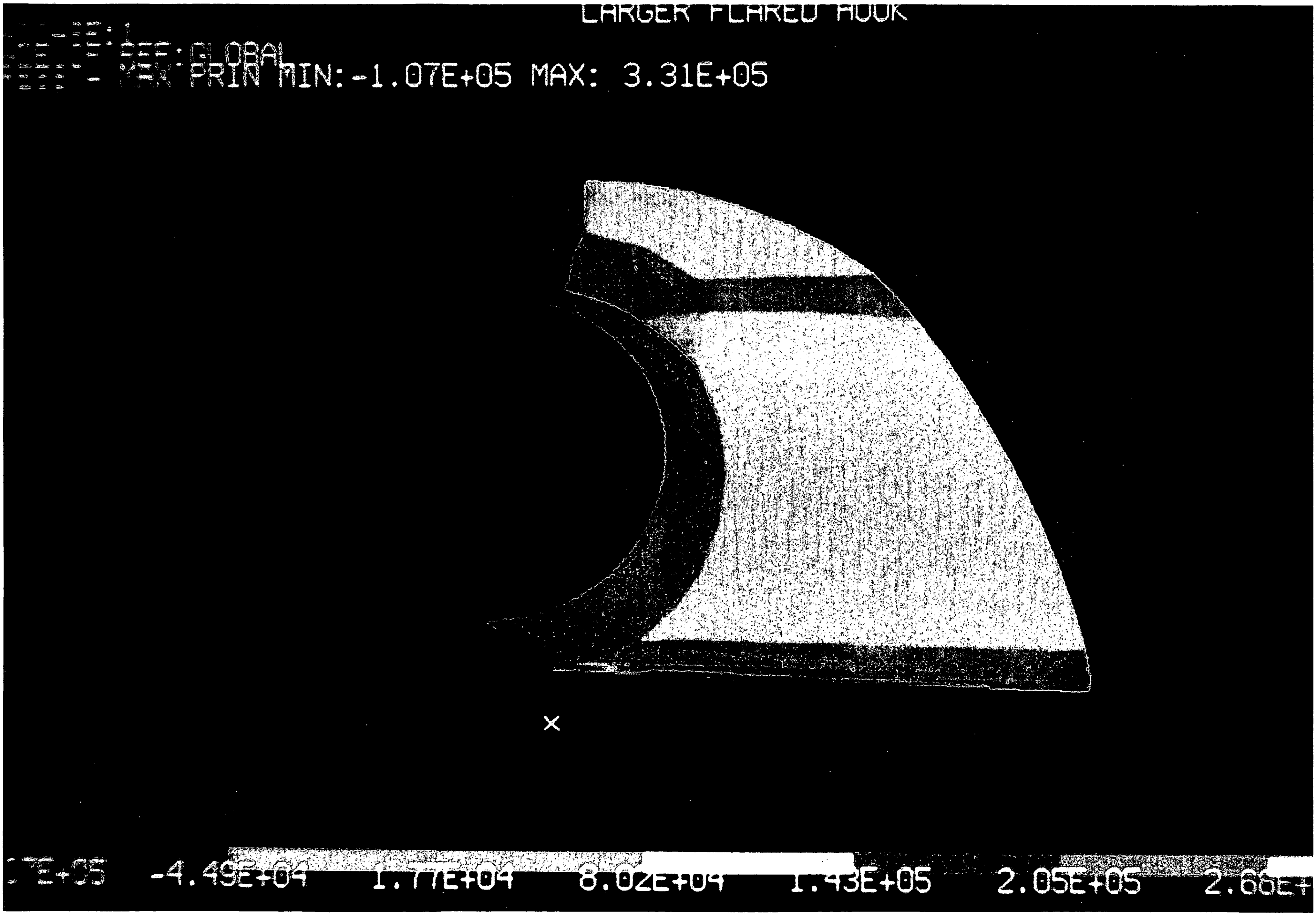

LARGER FLARED HOOK
REF: GLOBAL
PRIN MIN: -1.07E+05 MAX: 3.31E+05
-4.49E+04
1.77E+04
8.02E+04
1.43E+05
2.05E+05

Figure 4

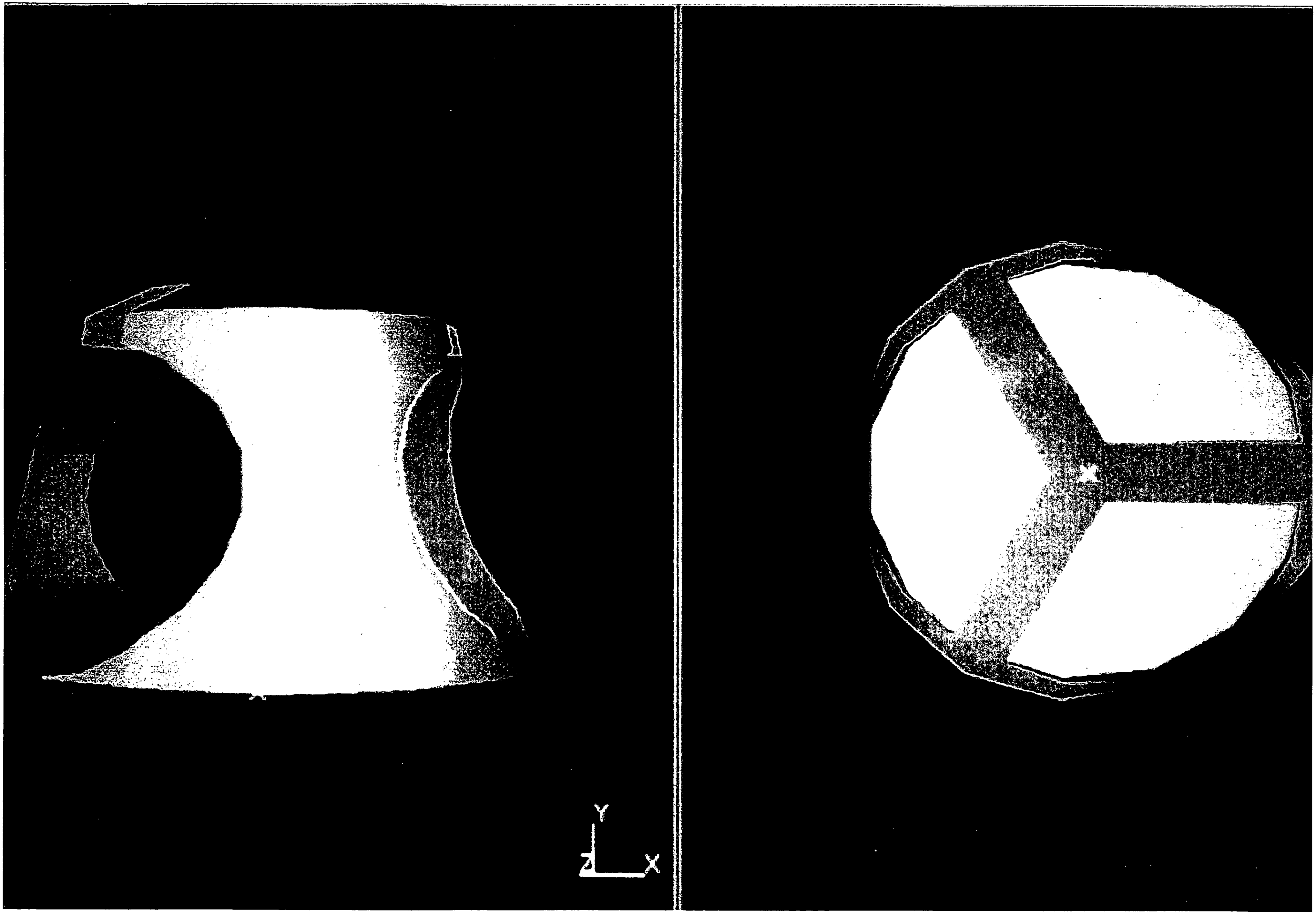



Figure 5

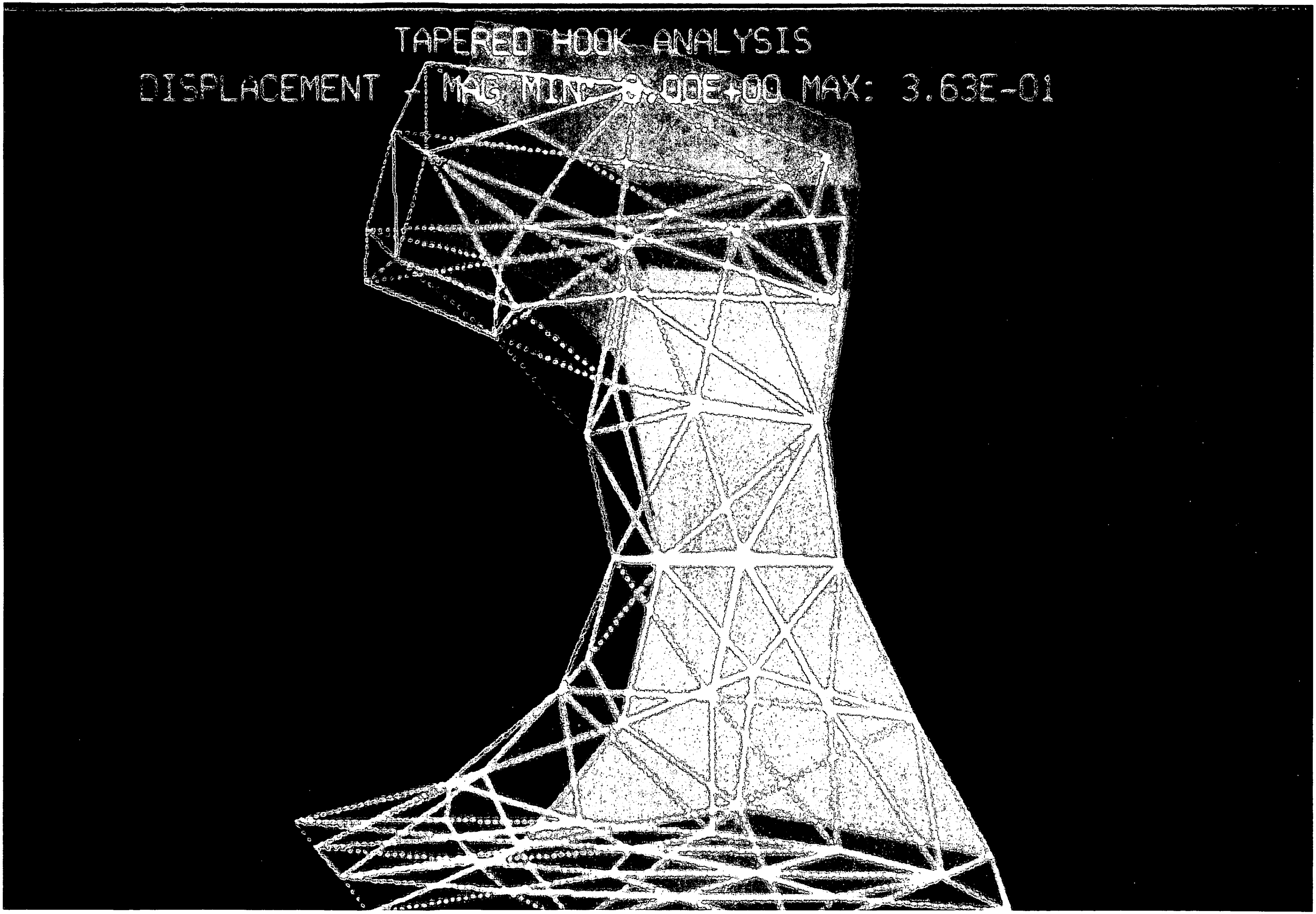

TAPERED HOOK ANALYSIS
DISPLACEMENT - MAG MIN: 0.00E+00 MAX: 3.63E-01

Figure 6

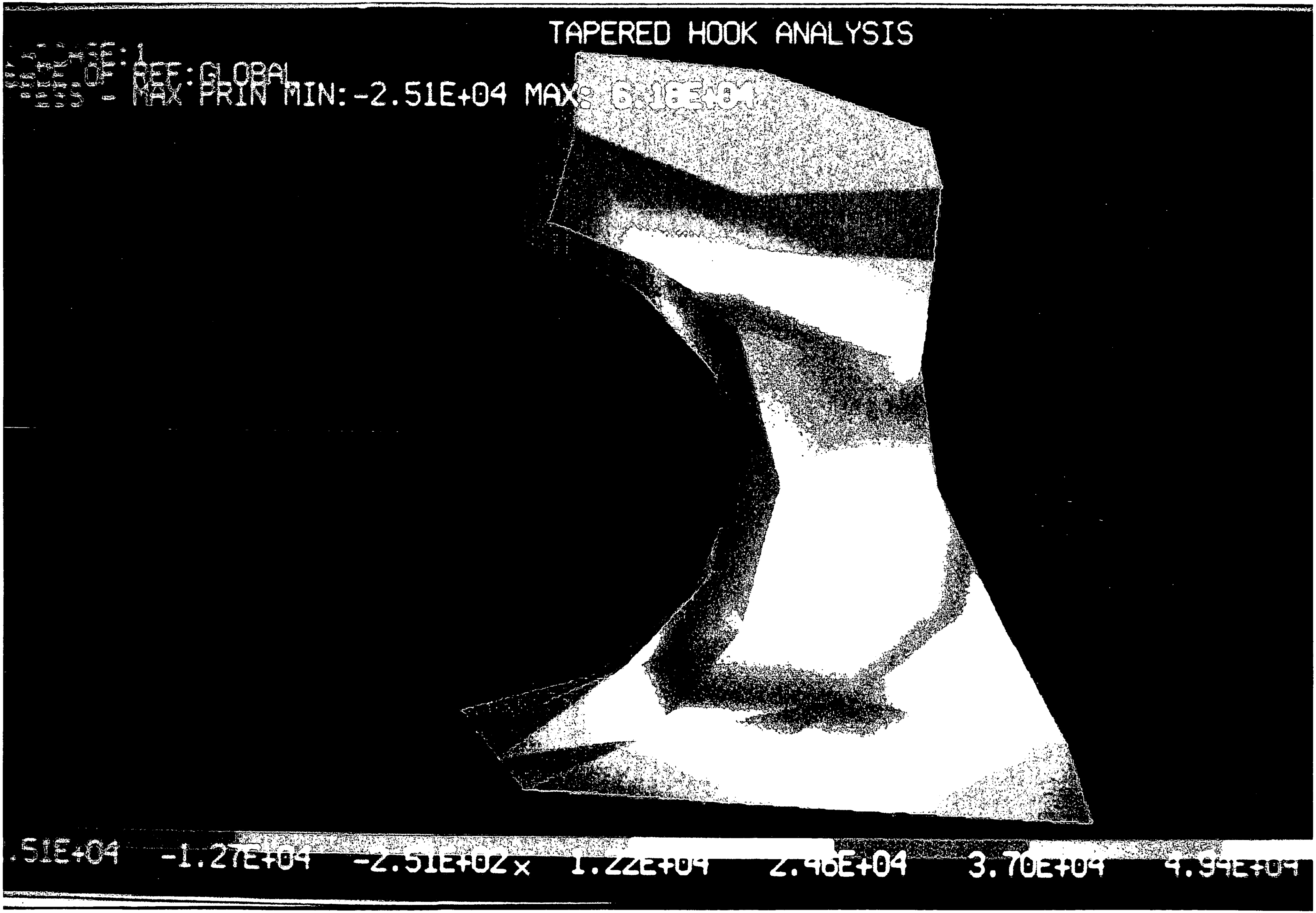

TAPERED HOOK ANALYSIS
REF:GLOBAL
MAX PRIN MIN:-2.51E+04 MAX: 6.18E+04
.51E+04
-1.27E+04
-2.51E+02
1.22E+04
2.46E+04
3.70E+04
4.94E+04

Figure 7

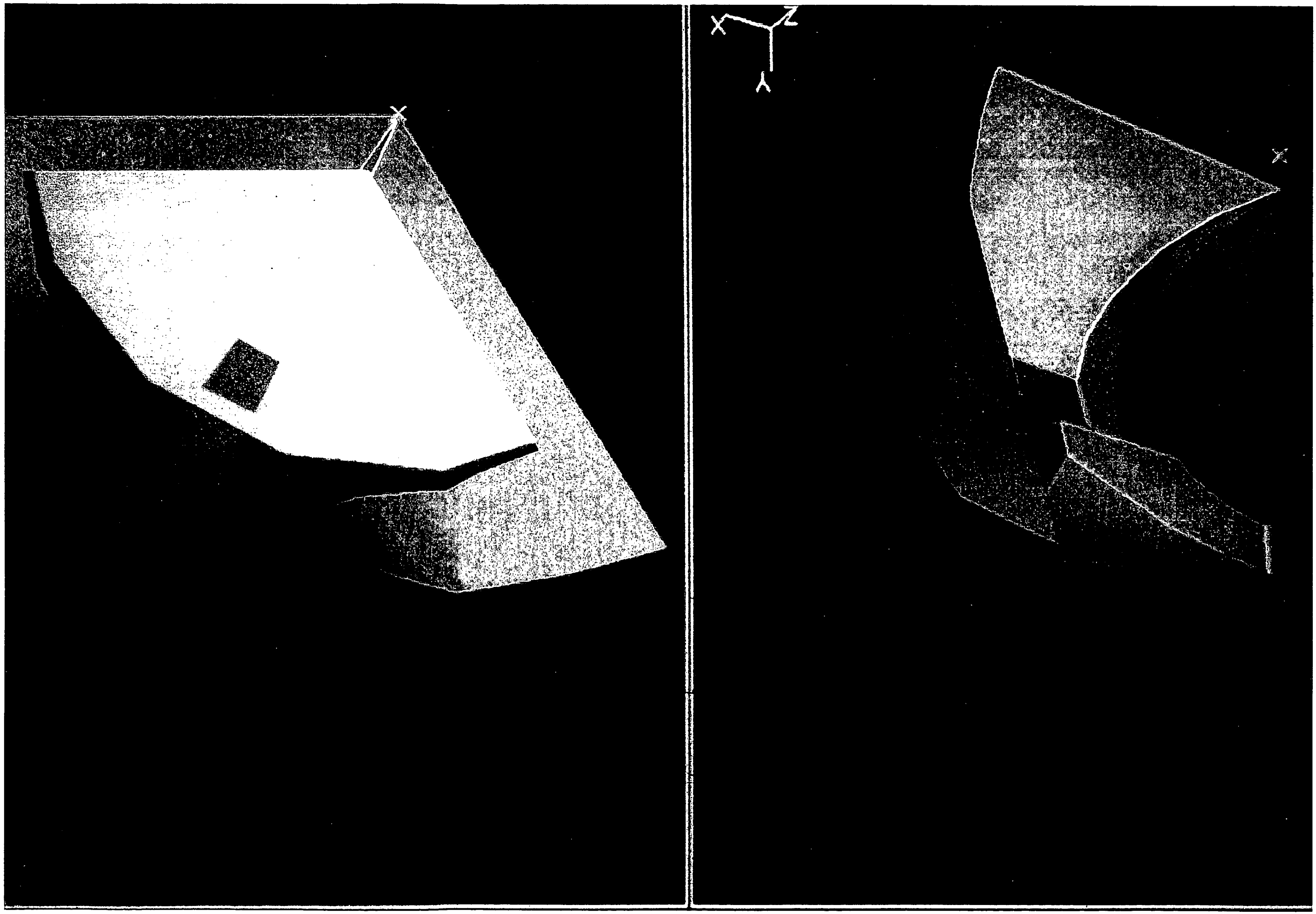



Figure 8

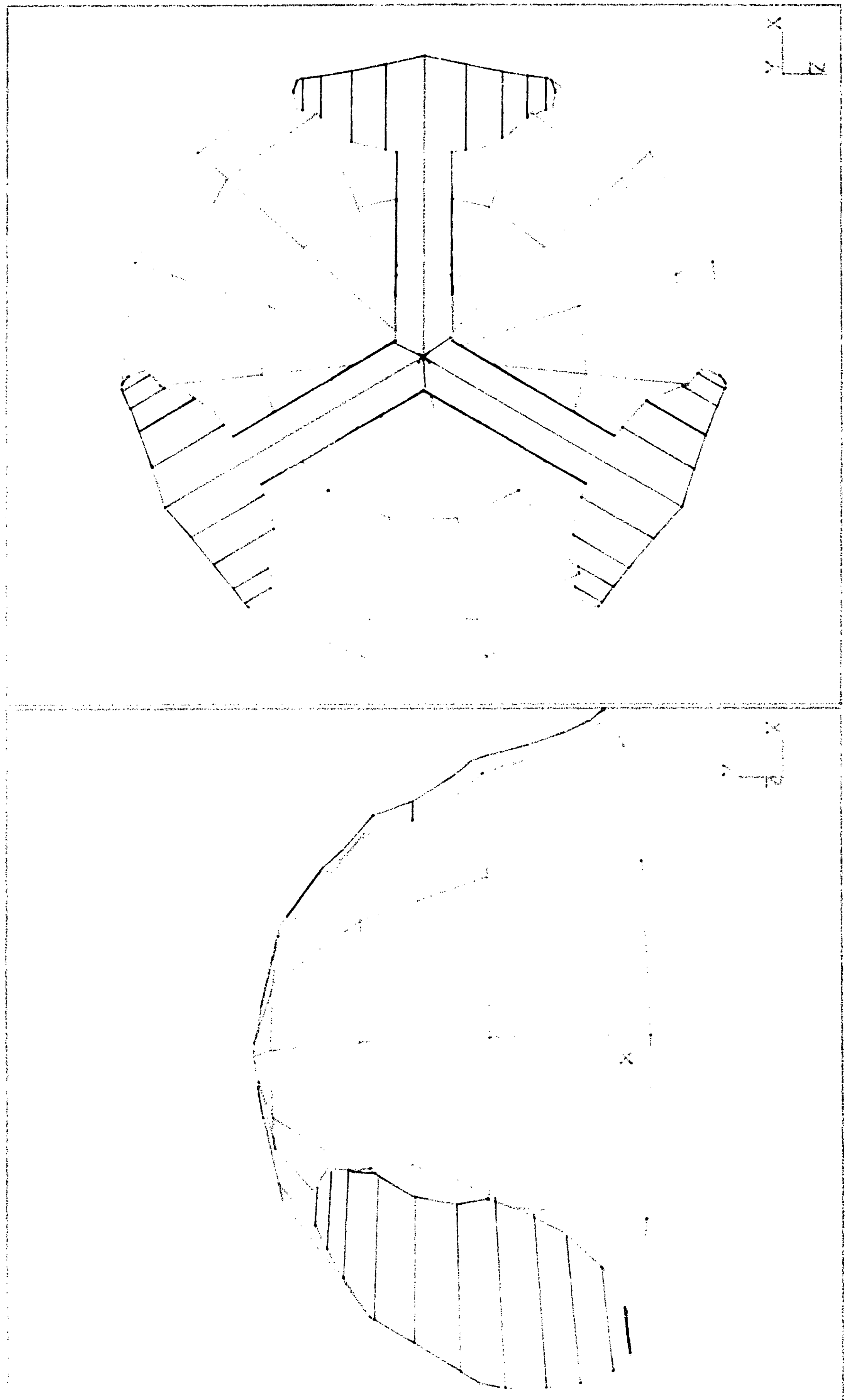


Figure 9

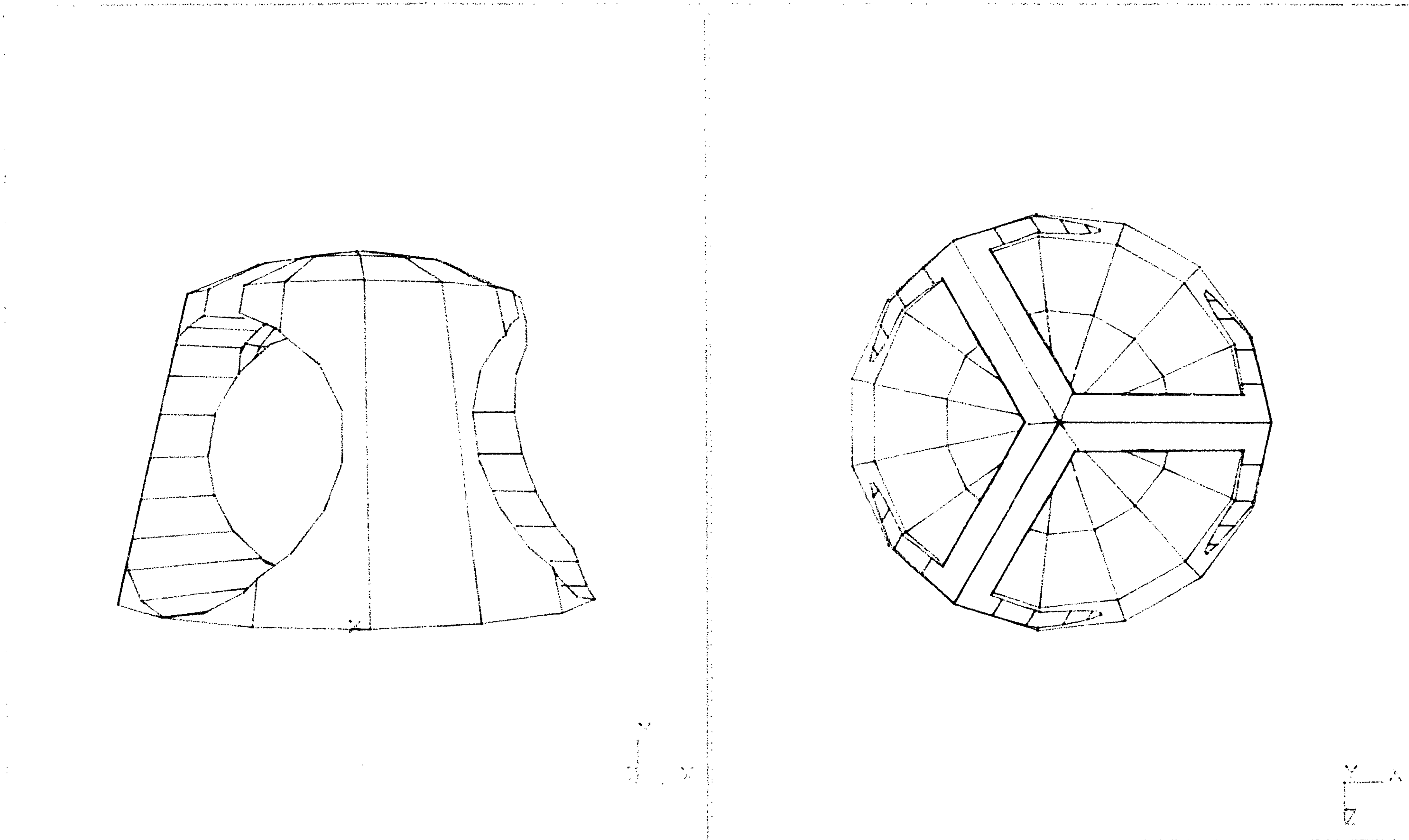


Figure 10

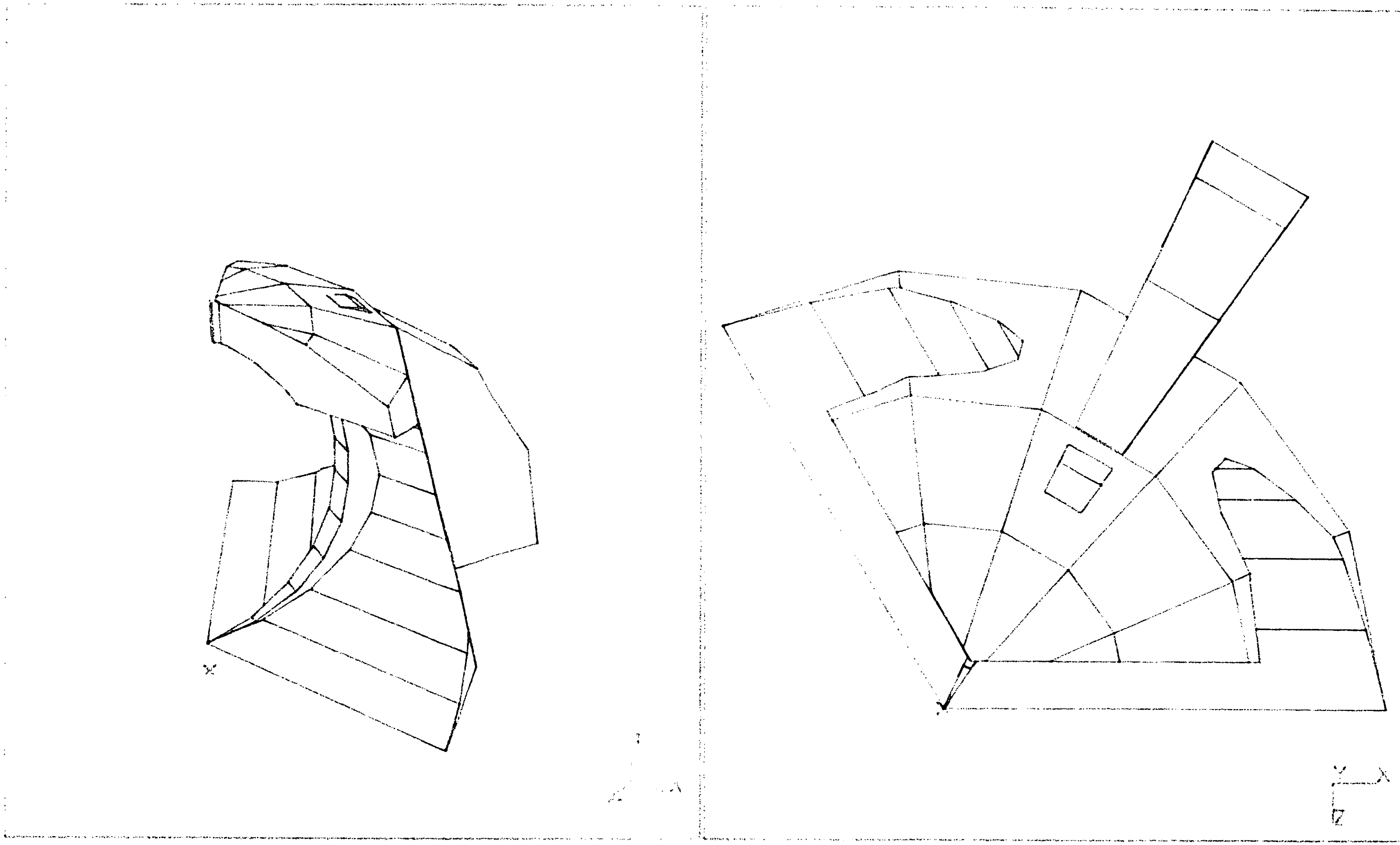



Figure 11

# APPENDIX C

## Design Matrix for Crane Hook

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | Total |
|---|---|---|---|---|---|---|---|---|
| Suction Cup | 0 | 2 | 1 | 2 | 0 | 1 | 0 | 6 |
| Velcro | 5 | 3 | 2 | 2 | 0 | 1 | 0 | 13 |
| C Hook | 5 | 5 | 0 | 3 | 5 | 5 | 5 | 28 |
| Elec. Magnet | 5 | 5 | 4 | 4 | 1 | 0 | 0 | 19 |
| Clamp | 5 | 5 | 2 | 2 | 3 | 4 | 2 | 24 |
| Wing Hook | 5 | 5 | 3 | 0 | 3 | 4 | 0 | 20 |
| Dome, 1 Hole | 5 | 5 | 2 | 2 | 5 | 5 | 5 | 29 |
| Dome, 2 Hole | 5 | 4 | 3 | 3 | 5 | 5 | 5 | 30 |
| Dome, 3 Hole | ***5*** | ***3*** | ***4*** | ***4*** | ***5*** | ***5*** | ***5*** | ***31*** |
| Dome, 4 Hole | 5 | 2 | 4 | 4 | 4 | 5 | 5 | 29 |

Constraints:
1. Work in a vacuum
2. Hold 2000 lb.
3. Ease of attachment
4. Ease of dettachment
5. Size
6. Work in environment
7. Work on end of line w/o power

Weights: 5 = Desirable
0 = Undesirable

# APPENDIX D
# PROGRESS REPORTS

**TO:** Mr. J. W. Brazell
**FROM:** Design Group #7. (SKITTER/Implement Mechanical Interface and Crane Hook Design)
**SUBJECT:** Progress report for week of April 11, 1988.

Each group member submitted one idea each for the interface and crane hook. In addition the following was accomplished:

Will Cash - Helped develop problem statement.

Alan Cone - Initialized search for materials.

Frank Garolera - Helped define design constraints.

David German - Aided in search for existing designs.

Dave Lindabury - Started considering practical use of ideas.

Cleve Luckado - Helped in consideration of ideas.

Craig Murphey - Helped develop problem statement.

Bryan Rowell - Aided in defining constraints.

Brad Wilkinson - Helped in search for materials.

**TO:** Mr. J. W. Brazell
**FROM:** Design Group #7. (SKITTER/Implement Mechanical Interface and Crane Hook Design)
**SUBJECT:** Progress report for week of April 18, 1988.

A general design for both the interface and crane hook were decided upon. In addition the following was accomplished:

Will Cash - Developed mechanical drawing of proposed interface.

Alan Cone - Continued search for library materials.

Frank Garolera - Considered alternate interface designs, and developed interface locking mechanism.

David German - Considered alternate hook designs.

Dave Lindabury - Developed CAD drawing of interface.

Cleve Luckado - Helped develop formal problem definition and used CAD.

Craig Murphey - Assisted in CAD use.

Bryan Rowell - Helped develop formal problem definition.

Brad Wilkinson - Aided in search for background information on interface.

**TO:** Mr. J. W. Brazell
**FROM:** Design Group #7. (SKITTER/Implement Mechanical Interface and Crane Hook Design)
**SUBJECT:** Progress report for week of April 25, 1988.

The group is currently in the information gathering mode of the design process. Hook-up motions were defined for the interface and it was decided that a latch or sliding hook must be used on all three points of attachement. In addition the following was accomplished:

Will Cash - Developed interface locking mechanism.

Alan Cone - Met with library personell and disscussed data base search.

Frank Garolera - Further design consideration on crane hook.

David German - Helped in data base search.

Dave Lindabury - Continued CAD work.

Cleve Luckado - Aided in crane hook development and CAD work.

Craig Murphey - Helped with CAD.

Bryan Rowell - Continued with search for materials.

Brad Wilkinson - Considered possible interface locking mechanisms.

**TO:** Mr. J. W. Brazell
**FROM:** Design Group #7. (SKITTER/Implement Mechanical Interface and Crane Hook Design)
**SUBJECT:** Progress report for week of May 2, 1988.

The format for the mid-term presentation was decided upon and color slides will be used of Apollo CAD drawings. Latching mechanisms were discussed. A final idea was decided for each the interface and crane hook in order to start analysis.

Will Cash - Created design matrix for interface designs and latch drawings for presentation.

Alan Cone - Directing library search and researching alternative designs.

Frank Garolera - Researching lunar effects on designs, physical model group member, helped with computer optimization.

David German - Coordinating data base search and physical model group member.

Dave Lindabury - Continuing Apollo CAD work and developing slides for presentation.

Cleve Luckado - Standardizing report formats, creating mechanical drawings, and physical model group member.

Craig Murphey - Personal computer work, Apollo modeling, and slide development.

Bryan Rowell - Researching all old design reports for interesting information and load parameter of previous groups.

Brad Wilkinson - Servo-actuator research , developed mechanical drawings of interface, and physical model group member.

**TO:** Mr. J. W. Brazell

**FROM:** Design Group # 7. (SKITTER/Implement Mechanical Interface and Crane Hook Design).

**SUBJECT:** Progress report for the week of May 9, 1988.

Will Cash - Researched on possible actuators, and analyzed the reaction forces that will be acting on the latching mechanism and the crane hook.

Alan Cone - Assisted David German in the library search, and researched patents that might help in the development of the latching mechanism and crane hook.

Frank Garolera - Participated in the continuing design of the latching mechanism, and researched several alternatives for the fabrication of a physical model for the crane hook.

David German - Continued the library search, developed a crane hook design matrix, and edited the previous progress reports.

Dave Lindabury - Redesigned the crane hook mate to allow the hemispherical hook to engage or disengage from any orientation, and initiated the finite element analysis for the new design.

Cleve Luckado - Searched for modeling patterns, and possible materials for the fabrication of a physical model for the crane hook and mechanical interface for SKITTER.

Craig Murphey - Assisted in the development of load characteristics for the finite element analysis and in the continuing design of the latching mechanism.

Bryan Rowell - Continued the research on previous projects to locate any information that might be relevant to the group's design.

Brad Wilkinson - Assisted in the search of possible materials for the fabrication of physical models and in the continuing design of the latching mechanism.

**TO:** Mr. J. W. Brazell
**FROM:** Design Group # 7. (SKITTER/Implement Mechanical Interface and Crane Hook Design).
**SUBJECT:** Progress report for the week of May 16, 1988.

Will Cash - Continued on the improvement of the latch design, and worked on the sizing of latch components for strength and minimum deflections.

Alan Cone - Searched and organized tools that will be required for the development of the physical models.

Frank Garolera - Participated in the search for suitable building materials for the mechanical interface, and edited the weekly progress report.

David German - Participated in the continuing design of the interface mechanism and the development of the physical models.

Dave Lindabury - Continued with the processing of the finite element analysis for the new crane hook design.

Cleve Luckado - Located materials for the fabrication of a physical model for the crane hook and initiated fabrication.

Craig Murphey - Assisted Cleve Luckado in identifying and locating possible materials for the fabrication of a physical model for the crane hook.

Bryan Rowell - Assisted in the search of possible materials for the construction os the mechanical interface for SKITTER.

Brad Wilkinson - Assisted in the continuing design of the latching mechanism and the search of possible alternatives for a physical model.

**TO:** Mr. J. W. Brazell
**FROM:** Design Group # 7. (SKITTER/Implement Mechanical Interface and Crane Hook Design).
**SUBJECT:** Progress report for the week of May 23, 1988.

Will Cash - Further work on actual sizing of latch components. Drawing for latch component. Compiled a portion of the rough draft. Research possible bearings for the latch.

Alan Cone - Assisted on the design of the new interface. Worked on rough draft and interface model.

Frank Garolera - Obtained data on materials for the design of interface and crane hook. Compiled and edited portions of the rough draft.

David German - Worked on the rough draft for the crane hook, and came up with alternative design for crane hook.

Dave Lindabury - Continued the process of finite element modeling for the crane hook. Established node-element model of hook on Apollo which will be transferred to F.E.A. solution and optimization.

Cleve Luckado - Assisted in the completion of crane hook model, and started the fabrication of interface model. Assisted in preparing the rough draft.

Craig Murphey - Obtained materials for crane hook model and for interface model. Finished crane hook model. Researched on actuators for actual designs.

Bryan Rowell - Researched material constraints for the construction of interface model. Also found several materials that meet design requirements. Worked on sections of rough draft.

Brad Wilkinson - Worked on the crane hook model and the design of the new interface/latching mechanism design. Assisted in the organization of rough draft.

**TO:** Mr. J. W. Brazell
**FROM:** Design Group #7. (SKITTER/Implement Mechanical Interface and Crane Hook Design)
**SUBJECT:** Progress report for week of May 30, 1988

<u>Will Cash</u> - Wrote text on latch components analysis and specifications, also assisted in production of latch model.

<u>Alan Cone</u> - Wrote and edited parts of crane hook report and assisted in production of interface model.

<u>Frank Garolera</u> - Edited parts of interface report and produced MacDraw figures to accompany component descriptions.

<u>David German</u> - Wrote and edited parts of crane hook report and edited all prior progress reports.

<u>Dave Lindabury</u> - Ran two FEA's on different crane hook designs, analyzed data for alternate solutions, and prepared slides for presentation.

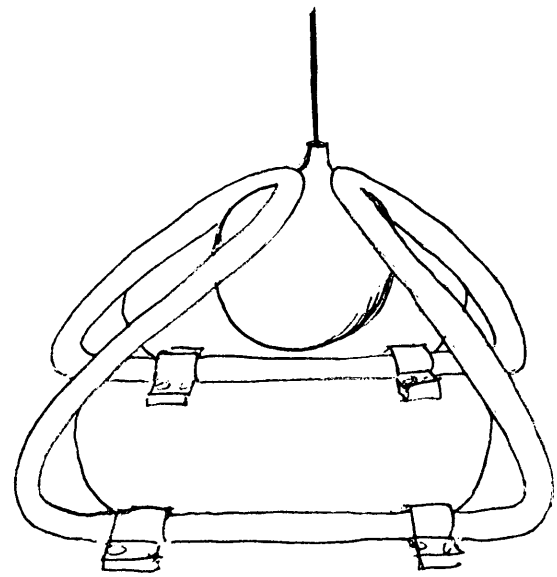
<u>Cleve Luckado</u> - Wrote parts of both reports, produced CAD drawings for interface, and assisted in production of interface model.

<u>Craig Murphey</u> - Wrote parts of crane hook report and assisted in completing both models.

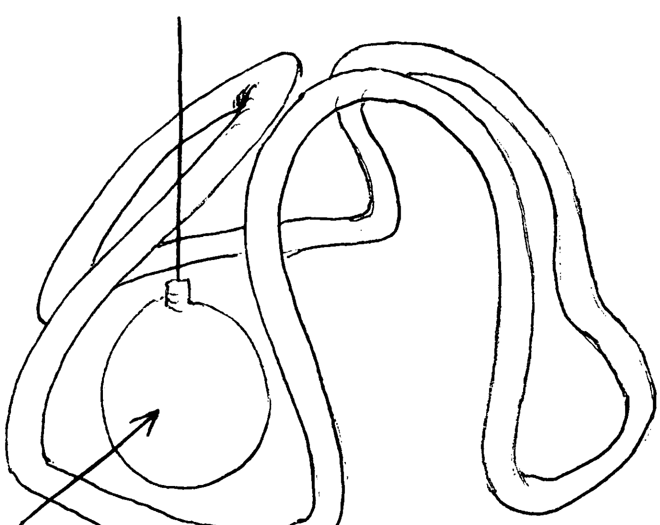
<u>Bryan Rowell</u> - Worked on materials, abstract, conclusions, and failure of interface report and prepaired for presentation.

<u>Brad Wilkinson</u> - Assisted in analysis of latch mechanism.

# APPENDIX F
# GRAPHICS OF THE WEEK



CRANE HOOK - ALTERNATIVES



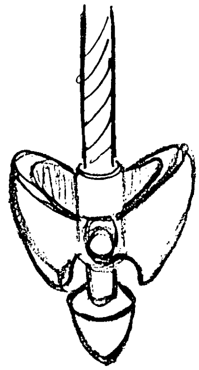
# CRANE HOOK


**ORIGINAL PAGE IS OF POOR QUALITY**

TROLL #7

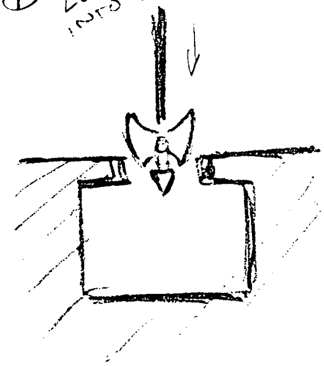
[illegible]

DAVE LINDABURY
ME 4182
GROUP 7

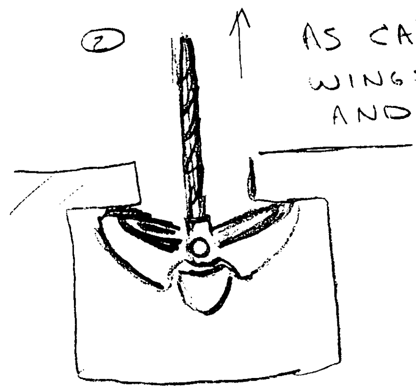


TWO OR MORE WINGS

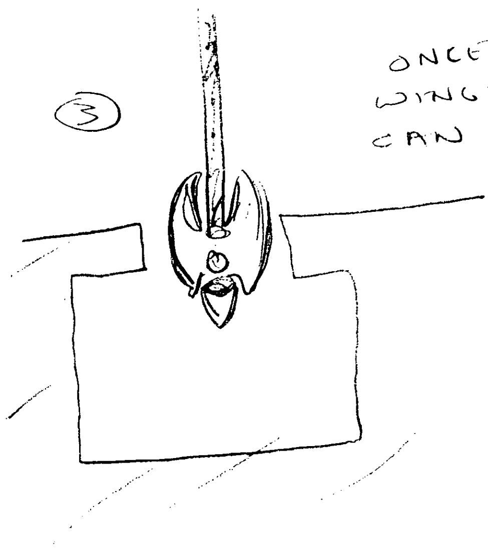
① HOOK LOWERED INTO HOLE



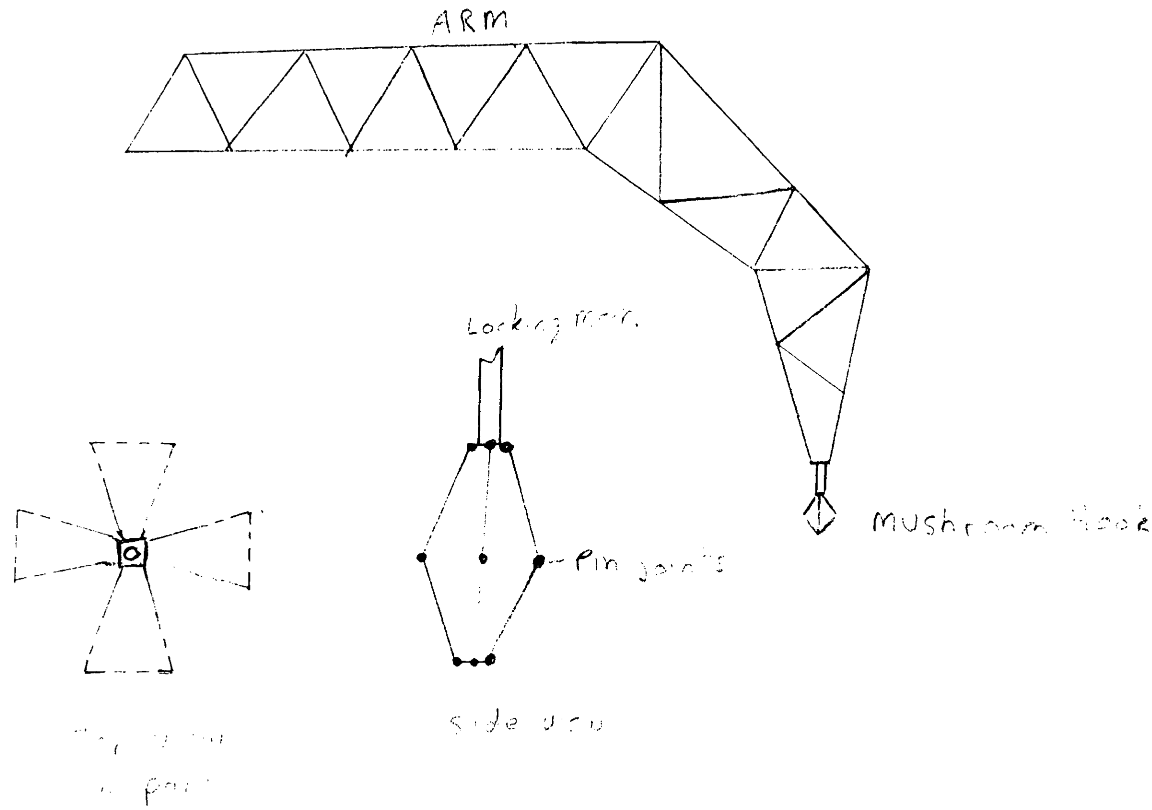
② AS CABLE IS PULLED UP, WINGS ARE FORCED OPEN AND CARGO LIFTED



③ ONCE CABLE GOES SLACK, WINGS FOLD AND HOOK CAN BE REMOVED.



# Crane Hook




This hooking device will be designed [illegible] to drop into a hole in a part and expand catching a lip on the hole. A locking mechanism will have two positions, locked up and locked down [illegible] with a manner of a [illegible] pen. The hook will be lowered [illegible] and compressed [illegible] [illegible] to [illegible] the hook [illegible] lock releases.

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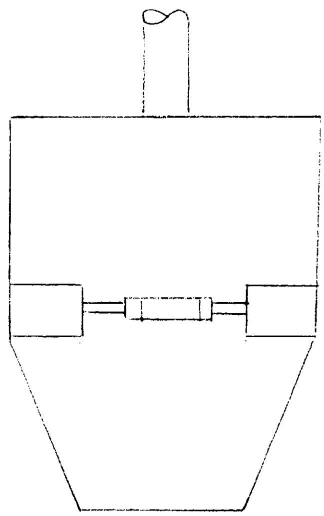
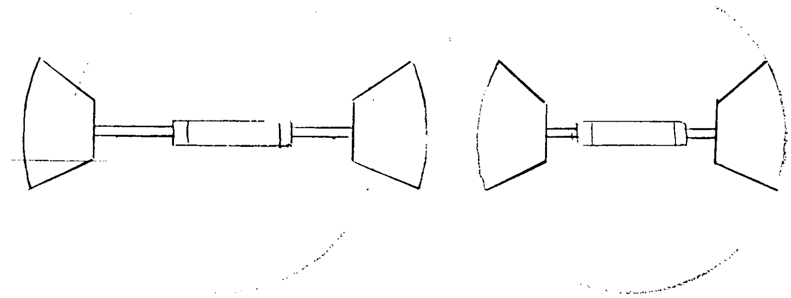
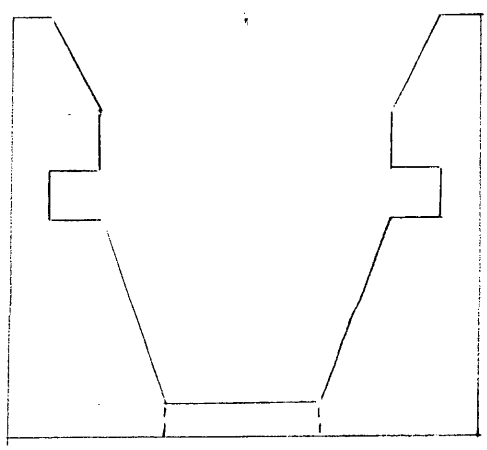
David [illegible]

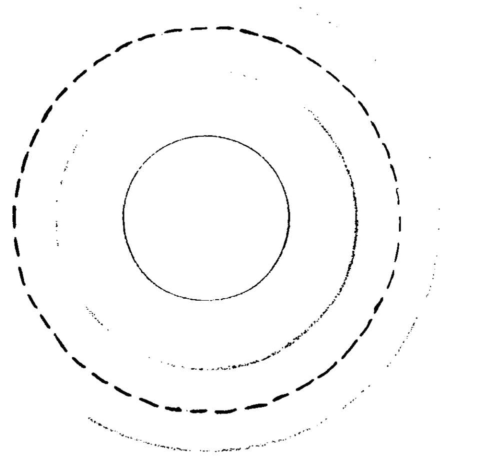
# II. CONNECTING IMPLEMENT (CRANE)

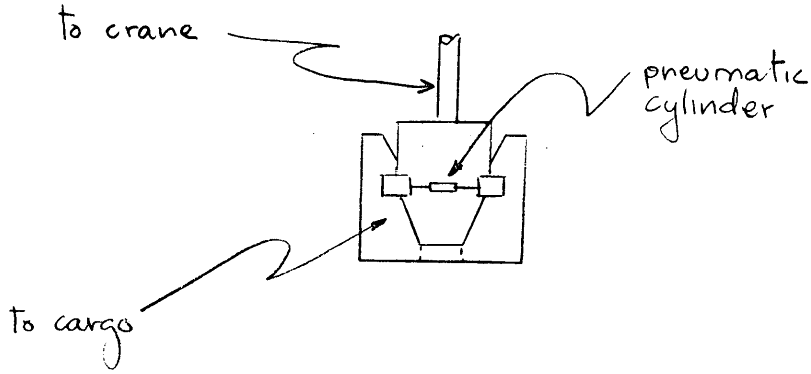




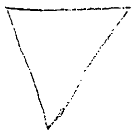
ENGAGED DISENGAGED







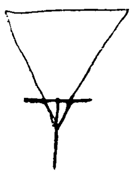
Crane Hook



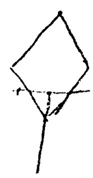
Triangle [illegible]

T on cargo

Triangle could be [illegible] around T Hook and rotated to position needed to hook together



Instead of Triangle the "hook" could be a diamond



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Craig S. Murphey
ME4182
Group 7
SKITTER/IMPLEMENT INTERFACE

Figure 1:

Figure 1 consists of a proposed [illegible] [illegible] [illegible] [illegible]. The design is made up of a dome [illegible] [illegible] [illegible] attached to load. Cut into the [illegible] of the dome [illegible] [illegible] [illegible] a slot [illegible] [illegible] the top of the [illegible] [illegible] to the top and center of the dome. A round ball can be attached to the end of the crane cable and then [illegible] simply re-positioning the boom, the ball can be slid into the dome. As long as the ball [illegible] [illegible] in the dome (by gravity acting on the load or by lifting the boom or cable), the crane will be capable of lifting the load. To disengage the device, the load is set down, the ball is lowered, and a simple movement of the boom will disengage the ball from the dome.

Figures 2,3&4:

A proposed design for the SKITTER/Implement Interface is shown. The male piece (Figure 2) would be connected near the corners of SKITTER's equilateral frame, and the female pieces (Figure 3) would be connected to the implement frame as shown in Figure 4. This set-up would be just as well suited for a top mount implement as it would be for a bottom mount implement.

To engage the interface, SKITTER would position itself over the implement and bend its leg joints to lower itself onto the implement. Once lowered, the SKITTER would rotate itself in either direction to allow the nipples (Figure 2) to move along and lock into the slots shown in Figure 3. To disengage, a bump and rotate by the SKITTER will separate the male & female pieces of the interface.

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# SKITTER/IMPLEMENT MECHANICAL INTERFACE AND CRANE HOOK

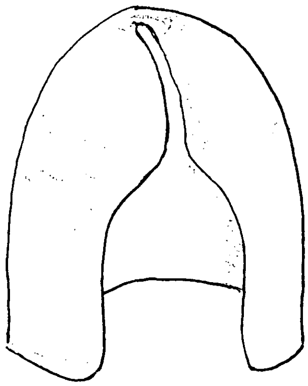

FIGURE 1

CRANE HOOK

(CRANE BALL NOT SHOWN)

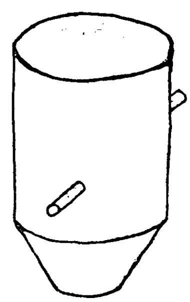

FIGURE 2

SKITTER/IMPLEMENT INTERFACE

(MALE SHOWN - TYPICAL 3 PLACES)

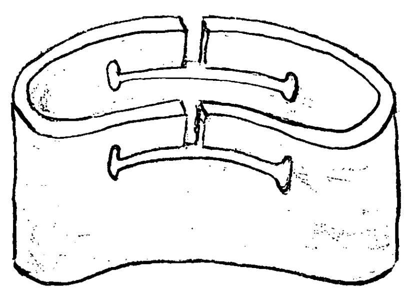

FIGURE 3

SKITTER/IMPLEMENT INTERFACE

(FEMALE SHOWN - TYPICAL 3 PLACES)

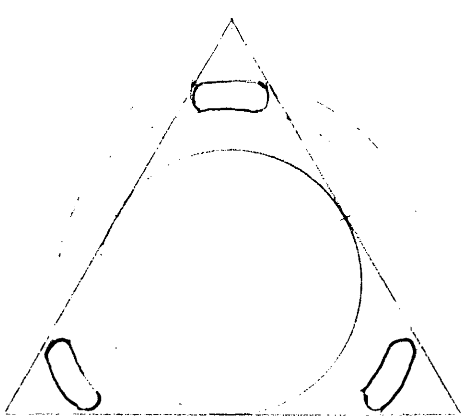

FIGURE 4

SKITTER OR IMPLEMENT - [illegible]

(POSI[illegible] E INTERFACE SHOWN)

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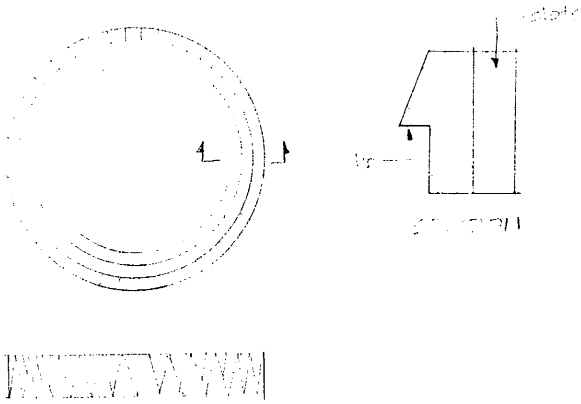
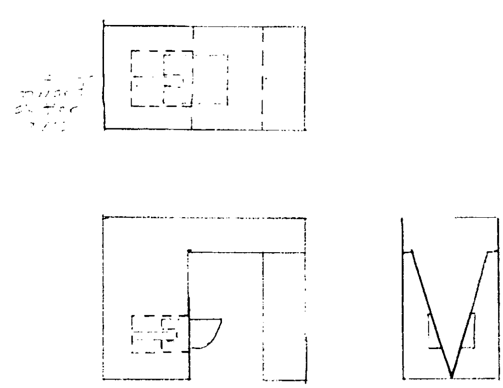
Craig S. Murphy
[illegible]
[illegible]

## [illegible] IMPLEMENT INTERFACE

[illegible] 4-13-88



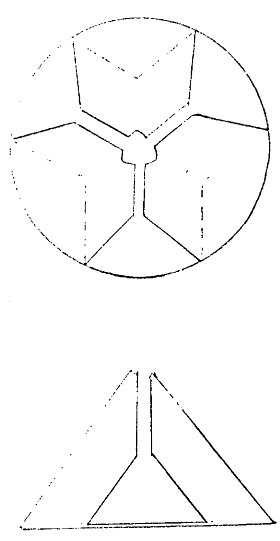
IMPLEMENT SIDE



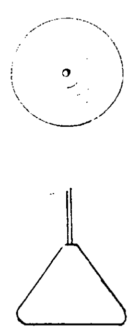
SKITTER SIDE

The ring is permanently mounted to the top of each implement. It has triangular slots around its perimeter and a lip facing downward. Skitter has a door latch type device at each of its 3 corner points. This has a triangular hook to fit into the ring. This allows skitter to grab the implement from any rotational position as long as it is centered over the ring. The latch is spring loaded outward. It locks into the ring. An actuator retracts the latch to release the implement.

## CRANE HOOK DESIGN



LOAD SIDE



CRANE SIDE

The cone-shaped hook is maneuvered into one of the three openings in the cone-shaped housing which is mounted on the object to be moved. The hook is prevented from swinging through the housing because of the triangular shapes. The notches catch the cable. The hook is then lifted into the top of the mount, restricting its movement. Note that the mount can handle various sized hooks and [illegible].

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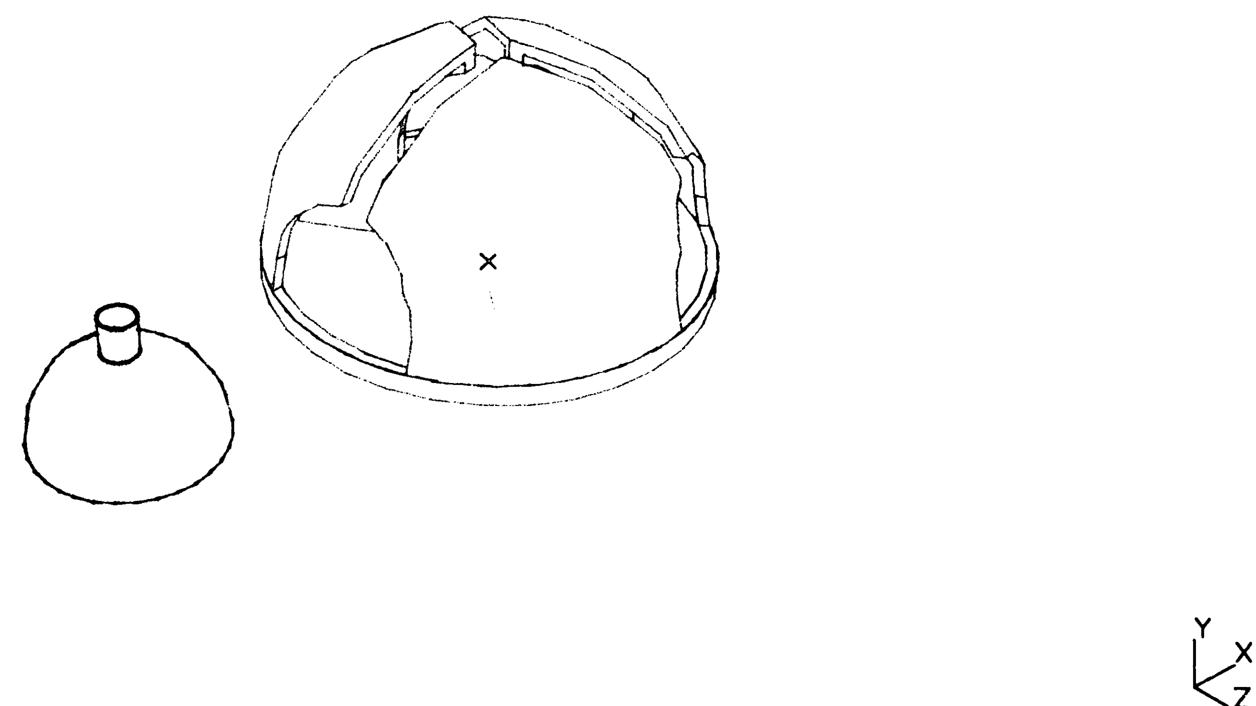
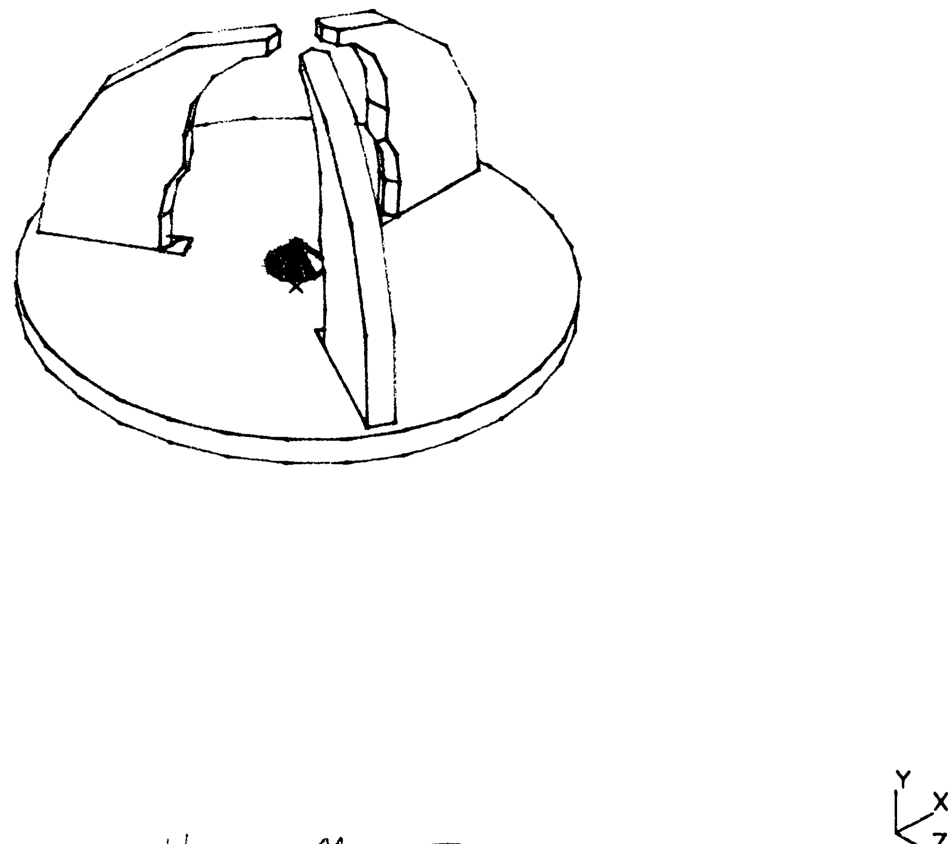
DAVE LINDABURY 4/21/88




CRANE HOOK AND MATE

Dave Lindabury 4/21/88




BASE AND RIBS OF CRANE HOOK MATE